Smart Meters – Selecting the core components to support metrology and circuit protection

Executive Summary

Across Europe, governments are embracing the need to implement smart meter initiatives. Some countries are further forward in deployment than others, while some have a more coherent plan for integration with the smart grid and for managing multiple utility services.

The European market for smart meters is extremely buoyant with deployment rates on the increase for the next four to five years. In this Whitepaper, we review the general state-of-the-art of the technology currently being deployed. In particular, the focus is on the critical components required to support the metrology, processing and communications subsystems. Current and voltage sensing and circuit protection are paramount, and solutions must be robust with a long life-time. Key components include sensors, passives, and speciality circuit protection devices. Specific examples and applications are included.

What makes a smart meter smart?

A smart meter is considerably more than a digital version of existing electromechanical energy meters, whether it be for electricity, gas or water. Not only should it provide more detailed information on energy consumption to both the local utility and the consumer, but it should also support two way communication. Bluetooth is typically the communication method of choice between the meter and the consumer's display unit.

Figure 1: Smart Meter

Benefits to the consumer include more accurate billing, greater awareness of historical and actual consumption, and the empowerment to cut energy bills, especially when connected to a smart home network or building management system. Two way communication with the utility will allow the consumer to take advantage of demand-side management services the utility might be able to provide, such as cheaper off-peak rates, plus integration with home or building automation systems will enable appliances to be controlled to avoid peak-time consumption.

Benefits to the utility are cost savings on manually reading meters, and improved energy management, ultimately reducing the carbon footprint. Demand-side management, which can lead to lower peak demand, can reduce the need for excessive energy generation and help reduce energy consumption overall. Savings of up to 10% on energy consumption have been reported, with emissions reduced by up to 9% [4].

However, the benefits of smart metering can only be accrued through the development of the smart grid. The smart grid is fundamental to a country's restructuring of its energy supply system, as it enables the shift away from wholly centralised generation to embrace renewables, such as solar and wind, from both large and small-scale producers. Weather sensing helps with the forecasting and managing of renewable energy, as countries come to rely less on nuclear, coal-fired or gas fired power plants.

The exploitation of two-way communication is as key to the smart grid as it is to smart metering. But there are some integration concerns,including voltage instability, bi-directional power, power quality, capacity constraints and load levelling or peak shifting. Data security is another area receiving considerable attention. Overall however, the smart grid, when combined with smart metering, is set to improve efficiency, reliability and security of electricity delivery. Outages and disturbances can be diagnosed and located faster.

Smart meter deployment in Europe

With this in mind, the EU issued a Directive in 2006, whereby EU member states are legally obliged to convert 80% of legacy energy meters to smart meters by 2020. Of the EU27, 17 nations planned a wide scale roll-out to meet or exceed the target by the deadline, including UK, Ireland, France, Netherlands, Spain, Italy, Austria, Poland and Greece [1]. Roll-out in France [3], for example, is running on schedule, and is committed to a 95% penetration by 2020.

But for some, the target has proved somewhat ambitious. The EU currently estimates that fewer than 72% of European consumers will have a smart meter for electricity and 40% for gas by 2020. The UK, for example, is behind schedule, expecting to reach just 75% deployment by 2020, with a significant number of those being first generation units with technical issues that need to be fixed.

Meanwhile, a number of countries, including Germany, Latvia and Slovakia, declared (under a clause of the Directive) that they would undertake a selective roll-out, following an economic assessment that determined it would not (yet) be cost effective for them to deploy smart meters on such as wide scale. However, Germany is now just beginning its selective roll-out of smart meters, initially to large consumers. This is part of a broader, longer term smart grid plan, with further targets set for 2024, 2032 and 2050.

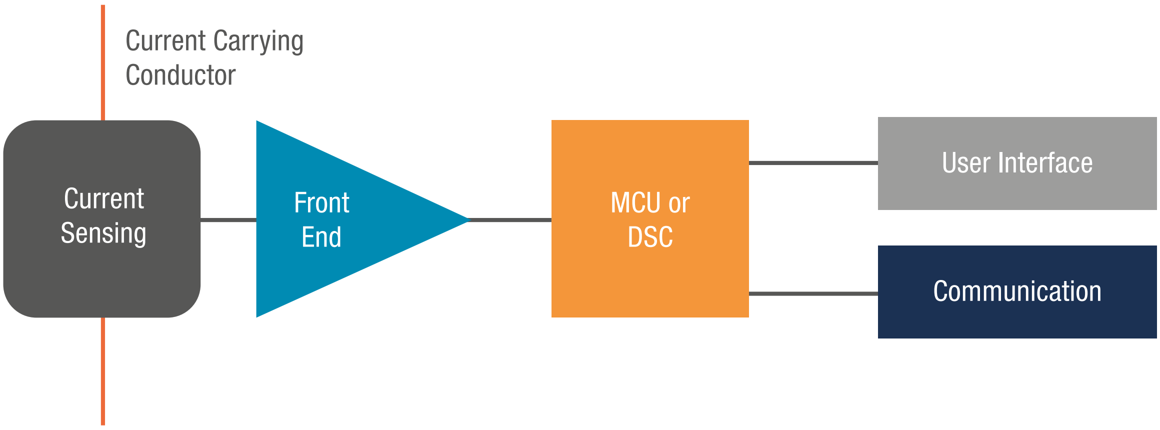
A number of concerns have beleaguered the roll-out throughout Europe. Some countries cite 'technical capabilities'. In particular, some early generation meters do not provide the detailed data to consumers that they should, or cannot be integrated with a home automation system. Some nations are finding it a challenge to ensure that smart metering becomes an integrated part of the smart grid. Data security is another critical issue Europe-wide and is being addressed by various bodies, including an EU Smart Grids Task Force [2].

However, despite the set-backs, the smart meter market is extremely buoyant. The next five years are expected to prove to be the most active in terms of smart meter deployment. Although less than 40% of Europe's (EU28+2) electricity customers had a smart meter installed at the end of 2017, forecasters expect that figure to increase to 70% by 2023. In some countries, a second wave of next generation meters will replace units employed initially [5].

What's in a smart meter?

The primary functional blocks of a smart meter comprise the metrology subsystem (current and voltage measurement), analogue front end (AFE) circuitry that converts and conditions the signal into a digital format, the processing section, user interface and the communication system. **See Figure 2.** Additional features typically include a power supply, real time clock and temperature sensor.

Figure 2: Functional blocks of a smart meter. [6]



Several manufacturers offer application specific microcontrollers and power conversion devices, together with reference platforms for smart meter design. The trend is towards a 'smart meter on-a-chip' which can combine processing, AFE, most of the metrology circuitry, security aspects and dedicated firmware and software, including the communications stacks. Dedicated communications subsystems for smart meters, including line driver and AFE, also exist, to suit various protocols and to meet required standards for specific markets.

In Europe, smart meters should meet the EN13757 M-bus standard for meter reading, to ensure interoperability between meters from different manufacturers. A wireless version is also specified, operating at 868MHz. Onward communication (internally to the building and/or externally to the utility) could be wireless, such as ZigBee, ISM band, broadband or cellular, Ethernet, or wired, using power line communication (PLC).

Further details on the above noted subsections are beyond the scope of this White Paper. Following, we will focus on a broad selection of the specialist components required in most smart meter designs. These include current and voltage sensing, passives, circuit protection and electromechanical devices.

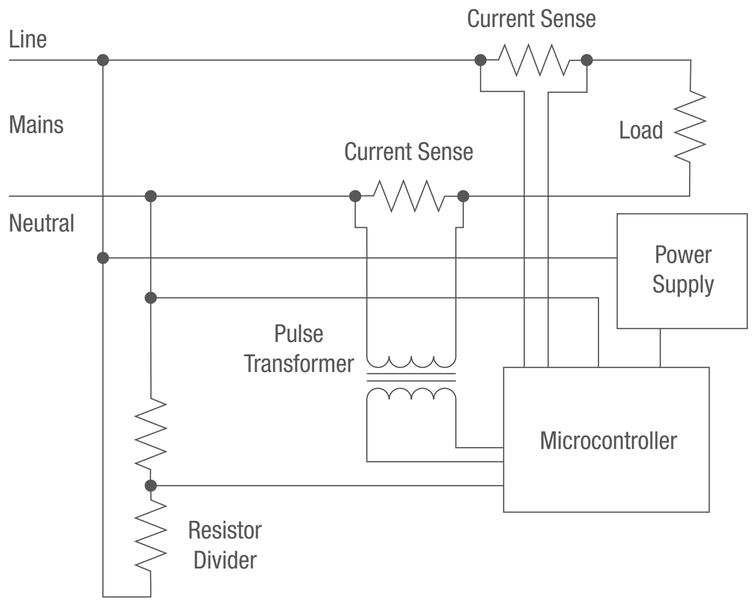
There are a couple of general points to consider when selecting components for a smart meter, particularly for measuring electrical power consumption. First, some of the circuitry will be connected to higher voltage equipment than is typical in consumer applications. Operating conditions might fluctuate, and therefore all the electronics has to be capable of operating reliably in harsh environments. Second, smart meters, and this includes battery-powered water and gas meters, are designed to have an expected lifespan of 25 years, making yet further demands on the quality and durability of the components. Another aspect is the selection of suitable RF components since the operating environment and the location of the meter might introduce high levels of electrical noise and low signal levels creating marginal operating conditions.

Current sensing

Starting with current sensing, shunt resistors are often selected as they can simplify the design, are low cost and give excellent linearity over a wide measurement range. When placed in series with a high current electric bus bar, the current flowing through it is calculated, based on the proportional relationship of voltage and current in a resistor of known value. Multiplying current and voltage yields the instantaneous power consumed at that time. Thus, the power consumed at any instant can be continually monitored by the microcontroller.

The shunt resistors need to be accurate in the range of a few hundred micro-ohms. Ideally, they should be an all-metal design with resistance values below 5 milli-ohms and TCR as low as possible. A range of suitable devices is available from companies including Bourns and Vishay. Bourns precision resistors, for example, enable accurate scaling and current sense, while their low PPM/oC characteristic results in stability over temperature variations. See Figure 3.

Figure 3: Various resistors are employed inside the smart meter for measurement. The resistor divider provides a voltage measurement to the microcontroller, and shunt resistors provide current sense measurements from each main to the microcontroller. Additional resistors may be included on signal and voltage lines to limit the supply current, thus preventing damage to other components. [7]



The Vishay WSMS devices, meanwhile, with their power metal strip construction provide high accuracy for smart meter applications and extremely low resistance values from 100micro-ohms to 1milli-ohm.

An alternative current sensing option is the current transformer, which is also low cost and offers minimal power dissipation, easy installation and high stability over both time and temperature. Immunity to interference is high. A typical solution is the Kemet C/CT-1216 clamp type current transformer. Features include a voltage output, thereby obviating the need for external resistors, low phase error of less than 1o, and a turns ratio of 1:3000 for accurate measurement over a wide current range of 0.1A to 120A.

Figure 4: Kemet C/CT-1216

Voltage measurement

In some smart meter designs, voltage measurement forms part of the metrology section. A resistor network can be used as a voltage divider. Typically, metal electrode leadless face (MELF) resistors are used, with accuracy better than 1% and TCR better than 100ppm. Designs will generally use up to 8 MELF resistors usually in resistance values above 100kohms. Look for the most robust components that can survive surges and maintain stable operation in all conditions. Metal film MELFs offer a combination of low thermal resistance, good pulse handling and low noise as well as electrical and environmental stability. Such devices are available from firms including TE Connectivity and Vishay.

For water meters, a capacitive-based pressure sensor such as the Sensata Ceramic Capacitive 100 CP series, converts water pressure into a voltage output that is linear across its operating range. Two capacitor plates are constructed one on a fixed ceramic substrate and one on a diaphragm that is subject to input water pressure. Applied pressure deflects the diaphragm plate, bringing it closer to the fixed plate and changing the capacitance value.

Figure 5: Sensata 100 CP series

Circuit protection

Smart meters contain sensitive electronics which require protection from overcurrent and overvoltage conditions, including transients (ESD) and power surges. The processing block and the communications systems are especially vulnerable. Protection devices are varied and can include transient voltage suppression (TVS) diodes, fuses, thyristor surge protectors, gas discharge tubes (GDT) and metal oxide or multilayer varistors (MOVs and MLVs). The power block may also require added protection, typically using inductors, bridge rectifiers, diodes and/or resettable fuses.

To protect input power circuitry generally, MOVs are favourite, with voltage ratings high enough to withstand the AC line voltage. However, in electrical meters, a thermally protected MOV (TMOV) is a safer option, particularly if the device might be subjected to a sustained abnormal overvoltage, limited current condition. TMOVs have the added benefit of disconnecting themselves from the circuit when they reach the end-of-life stage, unlike most standard MOVs, which can cause damage to themselves and pose a threat to the circuit. A range of TMOVs suitable for smart meters is available from Littelfuse, in 14mm, 20mm, 25mm and 34mm sizes, providing protection from 2kV to 20kV and beyond. Selection of the optimal device is based on the standards and specifications of the end application.

Meeting the need for long term capacitance stability in high humidity, high voltage and high temperature environments, the TDK EPCOS B3293 range of heavy-duty capacitors suit use as series capacitors used in the power supply for the meter. Unlike other X2 type capacitors used in high voltage power supplies. The B3293 capacitors are constructed using materials resistant to humidity.

TVS diodes are used for surge and ESD protection. They are often used in conjunction with MOVs, in designs where the power supply section also requires protection. They operate by clamping the fast-rising transients while the front-end MOVs absorb the bulk of the high energy from the transient. General purpose TVS diodes are available from a number of companies. Littelfuse, for example, recommends the SMAJ or SMBJ series for surge suppression on the I/O of the microcontroller. Similar parts in the TransZorb range are available from Vishay. Of particular interest for protecting power buses from 3 to 10kA, is the Power TVS range of diodes from Bourns.

Figure 6: TDK EPCOS B3293

MLVs are also used for overvoltage and ESD protection of circuits from low to medium energy transients. Connected between a data line and ground, in an overvoltage condition, the resistance decreases and the current rises exponentially, diverted away from the circuitry.

GDTs, meanwhile, are used to help provide high current surge protection for common signal transients. Typical devices include the Bourns Model 2097 high voltage (up to 2.2kV) version rated at 20kA, and the Model 2061/2063 which can handle 40 to 60kA.

To protect the wiring from catastrophic damage due to a short circuit, a fuse can be incorporated at the power supply's input. To meet electrical power meter safety standards, Littelfuse offers the 215, 514 and 835 Series of cartridge fuses.

Resettable positive temperature coefficient (PTC) fuses come in ceramic and polymer versions. To protect from power overcurrent conditions, polymer PTC resettable fuses are used. The Bourns Multifuse Series, for example, is available for currents from 50mA to 14A. The devices have negligible resistance during normal operation but react quickly with very high resistance to form and effective open circuit when the current or ambient temperature is above the rated level. When it comes to protection the processor block, the polymer PTC is ideal. The ceramic devices, meanwhile, are best suited to protect electronics that are subject to lightning strikes.

For more sensitive or higher performance systems, a protection device needs to react within nanoseconds, effectively blocking dangerous levels of transients almost immediately. The Bourns TBU High Speed Protector range fits the bill in this case.

Whatever communication protocols are used, wired or wireless, and this will depend on standards pertaining to geographic region, physical location (rural or urban), and the utility, protection of the communications subsystem will be necessary. Possible devices include TVS diodes, MOVs/MLVs, PTCs, fast acting fuses, GDTs and magnetics. Recommendations include a TMOV for a PLC port, but a TVS diode array with low parasitic capacitance for wireless interfaces such as GPRS, GSM or ZigBee. For Ethernet, RS232 or RS485 interfaces, a GDT combined with a thyristor surge protection device is an option. Littelfuse suggests the SEP series Sidactor protection thyristors with low parasitic capacitance.

Finally, a brief word on tamper proofing, or rather more accurately, tamper detection. The incorporation of a reed switch such as the Littelfuse 59166 or MDSM-4 series with a magnet or microswitch in the design, allows the meter to detect when the cover is opened. Reed switches are useful in battery-powered meters as they draw no power from the battery. A Hall effect sensor can be effective in detecting the use of strong magnets. In any case, the meter will send a message to the microcontroller, which in turn will alert the utility company.

Conclusion

The market for smart meters is booming in Europe as countries are ramping up their roll-out to meet 2020 deadlines and beyond. Designs have been evolving over recent years to iron out a number of technical issues that arose with early models. Careful component selection is critical to ensure meters meet European and national standards and specifications. In particular, robustness and long-life are essential. It is not only application-specific options for the processing core, AFE and communications subsystems that are holding the attention of designers. Sensors, passives, connectors and electromechanical devices require just as much consideration. Accuracy and reliability of current sensing plus circuit protection are paramount.

TTI components are found in smart meters around the world. The company offers a wide range of sensors, capacitors, resistors, specialist circuit protection devices, connectors, discretes, power supplies and electromagnetic components from a wide range of world-class manufacturers. A single source supplier, combined with dedicated supply chain programs, helps smooth lead times and manage inventory for optimum production efficiency.

[1] *Smart Metering Deployment in the European Union. https://ses.jrc.ec.europa.eu/smart-metering-deployment-european-union*
[2] *EU Smart Grids Task Force: https://ec.europa.eu/energy/en/topics/market-and-consumers/smart-grids-and-meters/smart-grids-task-force*
[3] *Smart meter roll-out in France: https://www.smart-energy.com/features-analysis/smart-meters-101-frances-linky-electricity-meters/*
[4] *EU on Smart Grids and Smart Meters: https://ec.europa.eu/energy/en/topics/market-and-consumers/smart-grids-and-meters*
[5] *ReportBuyer: Europe Smart Metering Market Report 2018-2023: https://www.reportbuyer.com/product/4220211*
[6] *Kemet*
[7] *Bourns (Page 7 of Bourns White Paper: Circuit Protection Solutions Optimised for Smart Meter Power, Measurement and Communications Port Protection.): https://www.ttiinc.com/content/dam/ttiinc/manufacturers/bourns/PDF/Bourns_CP_Smart_Meter_Power_Comm_White_Paper.pdf)*

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TTI, Inc. is the world's leading authorized distributor specialist offering passive, connector, electromechanical, discrete, power supplies and sensor components. TTI's extensive product line and supply chain solutions have made the company the distributor of choice for industrial, defense, aerospace and consumer electronic manufacturers worldwide.

TTI's extensive product line includes: resistors, capacitors, connectors, discretes, potentiometers, trimmers, magnetic and circuit protection components, wire and cable, wire management, identification products, application tools, power supplies, sensors and electromechanical devices. These products are distributed from a broad line of leading manufacturers. TTI strives to be the industry's preferred information source by offering the latest IP&E technology and market information through the online MarketEye Research Center. MarketEye includes articles, technical seminars, RoHS, seminars, industry research reports and much more.

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